Milk Production of Hand-Milked Dairy Cattle in Burkina Faso

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Abstract

The overall aim of the present thesis was to improve milk production and milking routines in Burkina Faso. There is a long tradition of keeping livestock in Burkina Faso and there are large numbers of cattle in the country. However, Burkina Faso today depends on the import of meat and milk, and the domestic production is greatly in need of improvement. The first in this thesis study was a survey that aimed to investigate the current situation in dairy farming and milk processing in peri-urban areas of Burkina Faso. Two experimental studies and two field studies were designed to answer questions arising from the survey. Day-to-day variation in milk yield and milk composition was determined in ten multiparous Zebu cows. Three different hand-milking techniques identified in the survey were compared in twelve Zebu cows, milked by three different milkers. A milk recording pilot study was carried out on ten farms, with a total of 79 cows. Finally, milk hygiene was investigated along the dairy chain, from the cow to the dairy or market.

The main constraints on milk production in peri-urban areas of Burkina Faso are low availability of feed and water, lack of selective breeding, milking management and lack of infrastructure. The milking routine was hand-milking and restricted suckling in both traditional and semi-intensive systems. The pilot milk recording data suggested it would be possible to improve milk production through selective breeding and that monthly milk recording would be useful for this purpose. The relative day-to-day variation in milk yield was much higher in hand-milked and restrictedly suckled cows (18-21%) than previously reported for machine milked cows (6-8%). Therefore, more frequent milk recording would be needed in order to use milk records for improving cow management. Three hand-milking techniques ("full hand grip", "thumb in" and "pull down") did not differ in their effects on teat treatment, milk yield or milk composition. However, different hand-milking techniques seemed to suit different milkers. Overall, low somatic cell counts were found in milk, which indicated good udder health. Milk was contaminated with bacteria directly after milking and the total bacteria count was dangerously high (10^6-10^7 cfu/ml) when the milk reached the consumers.

Keywords: Farm, Zebu, cow, milking, milk composition, milk processing, somatic cell count, restricted suckling, milk recording, milk hygiene.

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Dedication

To my Parents

To my Family
Kiswindsida Ursule
Frida Aurélie

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List of Publications

This thesis is based on the following papers, which are referred to by Roman numerals in the text:

I Millogo, V., Ouédraogo, G.A., Agenäs, S., Svennersten-Sjaunja, K. (2008). Survey on dairy cattle milk production and milk quality problems in peri-urban areas in Burkina Faso. *African Journal of Agricultural Research Vol. 3 (3), 215-224.*

II Millogo, V., Ouédraogo, G.A., Agenäs, S., Svennersten-Sjaunja, K. (2009). Day-to-day variation in yield, composition and somatic cell count of saleable milk in hand-milked zebu dairy cattle. *African Journal of Agricultural Research Vol. 4 (3), 151-155.*

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IV Millogo, V., Svennersten-Sjaunja, K., Ouédraogo, G.A., Agenäs, S. (2009). Raw milk hygiene and composition at farms, processing units and local markets in Burkina Faso (Submitted to Food Control, Elsevier)

V Millogo, V., Ouédraogo, G.A., Svennersten-Sjaunja, K., Agenäs, S. (2009). Pilot study on milk yield recording in hand-milked restrictedly suckled cows in Burkina Faso. (Short Communication Manuscript)

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Abbreviations

°C Degree Celsius
DM dry matter
FAO Food and Agriculture Organization of the United Nations
L Litre
mL millilitre
SCC Somatic Cell Count
USD United States Dollars

1 Introduction

Domestic animal production has proven to be a good source of food all over the world, and a rapid growth in milk and dairy consumption has been seen in many developing countries over the last ten years (FAO, 2002). However access to food still varies greatly between countries and continents. In Africa, for example, the problems of hunger and undernourishment remain to be solved (Atinmo & Oyediran, 2005).

Milk is produced by all mammals; for human consumption mainly by goats, sheep, cattle, buffaloes and camels and 90% of the milk consumed by humans is from dairy cattle (FAO, 1990). Cattle milk production has been greatly improved by selective breeding and feeding (See review of Shook, 2006) and management practices (see review by von Keyserlingk *et al.,* 2009), and today it is not uncommon for cows of high yielding breeds, like the Holstein-Friesian, to produce 12,000 kg milk in one lactation (Jorritsma *et al.,* 2008). The Holstein-Friesian dairy breed is leading the way in milk yield and is common in many parts of the world, however, its adaptability to hot tropical climates has been questioned, especially in countries where the need for dairy products is increasing most rapidly (Delgado *et al.*, 1999).

In tropical areas Zebu (*Bos indicus*) are the most widespread and well-adapted type of cattle. In Africa there are many different types of Zebu belonging to the same genotype and known under different names (Belemsaga *et al.,* 2005). The production capacity of Zebu cows varies between countries and between different management conditions. Lactation yields of 800-1,300 kg milk have been recorded for different breeds of pure Zebu in Africa with high nutrient intake (Das, 1999; Boly *et al.,* 2001; Yilma *et al.*, 2006). In Burkina Faso, lactation yields in Zebu cows have been reported to vary between 500 and 1,000 kg per lactation under practical farming conditions (for review see Hamadou & Sanon, 2006), and the Zebu cow is able to survive harsh nutritional conditions (Grimaud *et al.,* 1999). Milk production in Zebu has not been studied in the same detail as in Holstein-Friesian, and opinions differ on the milk production capacity of Zebu cows and their genetic potential.

Eighty percent of the active human population of Burkina Faso is involved in agriculture, and there are estimated to be around seven million cattle, seven million sheep and ten million goats in the country (MRA, 2004). Despite this, Burkina Faso is unable to satisfy its own demand for dairy products, and large quantities of powdered milk have to be imported (for review see Proulx & Ouédraogo, 2006). The import of milk powder is generally considered to have a negative impact on the development of domestic milk production. For example, estimated milk consumption was 12.4 kg equivalent milk/person/year in the main cities of Burkina Faso, of which 85% was imported (see review by Hamadou & Sanon, 2006). The imported milk powder is more widely available and cheaper for consumers (see review by Proulx & Ouédraogo, 2006).

Meat and milk from livestock are important food sources for the people of Burkina Faso, as in many African countries with growing populations (Delgado *et al.,* 1999). However, developing milk production is complex and requires a sustainable plan (Barron del Castillo, 1990). Various efforts have been made to improve production (see review by Hamadou & Sanon, 2006) but 95% of the milk produced still comes from traditional production systems using indigenous breeds. Crossbreeding has been promoted to improve the low milk yield of indigenous cows but failures have been observed, often explained by a low technical capacity to apply artificial insemination (FAO, 1996). Furthermore, problems with feeding (Ouédraogo-Koné *et al.,* 2006; Sanon *et al.,* 2007), milk hygiene and milk processing (Hamadou *et al.,* 2004) still need to be addressed.

1.1 Livestock production systems in Burkina Faso

Livestock production in Burkina Faso is based on grazing systems (Pagot, 1985) and is the second largest agricultural activity after cotton production. Nineteen percent of Burkina Faso's export products are from livestock production (MRA, 2004), which comprises 12% of the gross domestic product.

Traditional nomadism, in which animals and their keepers move from area to area without returning to the previous area (Pagot, 1985), still exists but is disappearing and being replaced by other production systems. Some farmers move with their animals between two areas, depending on the season, a practice called transhumance (Kagoné, 2004). However, available land is limited and farmers are starting to own land themselves and carry out year round milk production, referred to as the sedentary system. There are sedentary farmers in peri-urban areas that use a semi-intensive production system characterized by indoor housing for animals, cross-bred cows and use of artificial insemination, however this practice represents less than 1% of farmers in Burkina Faso (Hamadou *et al.*, 2002).

Today only few farmers can make economic investments. Those who do, view farming as a business opportunity (Marichatou *et al.,* 2002) and generally lack a farming background. On most farms, peak milk production has been estimated at 2-3 L/cow/day in the rainy season (Sidibé *et al.,* 2004), but figures of up to 10 L/cow/day are reported from semi-intensive farms (Hamadou *et al.*, 2002). Overall it can be summarised that the possibilities to improve dairy production in Burkina Faso have not been investigated in great detail.

1.2 Milking routines

In Burkina Faso, the tradition is to milk lactating animals by hand. Different hand-milking techniques and routines are practiced, but their effects on udder health and production have not been evaluated. Farmers know that a healthy cow that has enough food, shelter and water will still not produce well unless she is calm and comfortable. In general, milking takes place in the shade of a tree, near the living house or in a cowshed. The milking equipment and storage materials vary between farms, but most traditional farmers use calabashes for collecting and storing the milk.

In production systems where milk is used for family consumption and beef production, the calf is allowed free suckling. However, where the farmer aims to sell the milk, the calf is used for stimulation of milk ejection and is allowed to suckle only for a limited time. Thus the calf usually meets its dam only during milking. This system has been described in different tropical production systems and is generally referred to as restricted suckling (Das *et al.,* 2000; Sandoval-Castro *et al.,* 2000; Fröberg *et al.,* 2007). Suckling for 45 minutes after milking has recently been tested in Burkina Faso by Sidibé-Anago *et al.* (2008) and was found to decrease fat content in saleable milk. Further knowledge about the effects of restricted suckling systems on milk yield and lactation length would be valuable for the development of milk production in Burkina Faso.

1.3 Seasonal variation in milk production

The main feeding system for livestock production in Burkina Faso is based on natural pasture, so milk production depends on pasture quality and availability. The cows' reproductive cycle is also related to the seasons, with calving predominantly in the rainy season (see review by Abeygunawardena & Dematawewa, 2004). The availability of natural pasture during the rainy season results in slightly higher milk production of lactating cows compared with the dry season (Sidibé *et al.,* 2004). However the shortness of the rainy season and poor pasture quality during the long dry season make all year round milk production difficult (Kaboré-Zoungrana *et al.,* 1999).

Hay and crop by-products such as cottonseed cake have been used as feed for lactating cows, but the practice is still uncontrolled and considered to be expensive for farmers (Sidibé-Anago, 2008). Controlled feeding can contribute to maintaining regular milk production. According to an unpublished study (Unpublished, Oudet, 2005), the lack of regular milk supply from farms is one of the most serious obstacles to the development of milk processing in Burkina Faso. One consequence is that the local milk market is not well developed because seasonal variation in milk production gives an uneven availability of milk for marketing.

1.4 Marketing and milk processing

Without processing, milk is difficult to handle, conserve and sell. In Burkina Faso, as in many parts of Africa, unpasteurized fresh milk is sold on the local market (Gran *et al.,* 2002; Bonfoh *et al.*, 2006). The problem is that the quality of this raw milk is uncontrolled, and the key issues for milk hygiene are not well described. Although fermented milk and butter are easier to conserve than raw milk, in rural areas raw milk is mainly sold in exchange for millet or other products, often by women (Querre, 2003).

In traditional livestock production systems, milk is often processed by farmers into butter, fermented milk and cheese (Kagoné, 2004). Some family processing units were set up in Bobo-Dioulasso prior to 1972 (Le Troquer, 1993) with yogurt, fresh cream and pasteurized milk as the main products, sold in Burkina Faso and neighboring countries. There were no semi-industrial dairy factories in Burkina Faso before 1990 (see review by Hamadou & Sanon, 2006) and, even since 1990, milk processing has not achieved its expected development.

The increased demand for dairy products in urban areas in many countries has raised consumer awareness about product quality (Barron del Castillo, 1990), including nutritive value and hygiene. Under local conditions in Burkina Faso, the hygienic quality of milk between farm and processing is not clearly controlled, and the condition of the milk when it reaches the consumer is often unknown.

There are many household processing units but very few semi-industrial dairy factories in Burkina Faso (see review by Hamadou & Sanon, 2006). These processing units suffer from an uneven supply of raw milk and often have financial problems. Moreover, most of the units process more imported powder milk than local raw milk (Marichatou *et al.,* 2002; see review by Hamadou & Sanon, 2006).

1.5 Breeds for milk production and genetic improvement

The dairy breeds commonly used in Burkina Faso belong mainly to the Zebu species (*Bos indicus*) (Cunningham & Syrstad, 1987). Most individuals are of Zebu breeds indigenous to Burkina Faso, but there are also non-indigenous breeds, mainly Gudali and Azawak (*Bos indicus*). In addition, *Bos taurus* breeds are kept, mainly by farmers in the South-West of the country, the most common being Baoulé and N´dama. There are also various crossbred cows. According to FAO (1987), the *Bos indicus* and *Bos taurus* breeds in Burkina Faso can be described as follows:

External traits of *Bos indicus*

The external trait that most clearly separates *Bos indicus* from *Bos taurus* is the hump over the shoulders or the posterior part of the neck. The size and shape of the hump varies with breed, sex, and age of the animal. Other conformation traits common to most *Bos indicus* are a narrow body, a sloping rump, and long legs. The size of the animal varies over a wide range; for example the average weight of Zebu Peul Sudanese in Burkina Faso ranges from below 200 kg to over 400 kg for mature cows (Mémento de l'Agronome, 1993).

External traits of *Bos taurus*

The only major populations of humpless cattle native to the tropics are found in West Africa and Latin America (FAO, 1987). The West African types consist of several breeds of small, short horned cattle. The best-known representative is the N'Dama, found in Guinea and neighboring countries. The animals are small in size (body weight of mature cows around 200 kg) but very hardy. N'Dama and some other breeds of the same group are known to be highly resistant to bovine trypanosamiasis, and are consequently regarded as an important genetic resource (Cunningham & Syrstad, 1987). Trypanosamiasis, a disease caused by protozoa of the genus Trypanosoma, (mainly *T congolense*, *T vivax, T brucei* and *T simiae* (Chiurillo *et al.,* 2002) and vectored by the tse-tse fly (*Glossina spp* (Bouyer *et al.,* 2005) affects all domestic animals and is very common in tropical sub-humid areas such as the West of Burkina Faso.

Genetic improvement

Today, there is no breed selectively bred for milk production in Burkina Faso (Kouakou, 1997) and as in many African countries, crossbreeding is often regarded as an alternative to selective breeding. It has been reported that the Zebu genotype has been used in crossbreeding to develop dairy production systems suitable for hot climates but success has been limited (Hansen, 2004). The current opinion on Zebu cow milk production is not favorable (Jenet *et al.,* 2004) because of the low milk yield even when long-term high nutrient intake is available. However, results from Zebu milk yield studies in Africa, Brazil and India suggest that it may be possible to achieve higher yields than those typically reported if nutrient intake and milking management are improved (Silvia & Del Lama, 1997; Das, 1999).

Zebu milk production in Africa

Several studies have been carried out on milk production in Zebu cows and their crosses (Coulibaly & Nialibouly, 1998; Das *et al.,* 2000; Masama *et al.,* 2003; Ahmed *et al.,* 2007). Higher yields and longer lactations were found in crosses between Zebu and Holstein or Jersey (Ahmed *et al.,* 2007). Saleable milk yield for crossbred Zebu×Holstein was estimated to be 2,700 kg milk per lactation (Ahmed *et al.,* 2007) compared with 1,000-1,300 kg for pure Zebu cows (Yilma *et al.,* 2006). Furthermore, the lactation length was 270 days for Zebu×Holstein (Ahmed *et al.,* 2007) as opposed to 200 days for the pure Zebu (Yilma *et al.*, 2006). It has been proposed that crossbred cows could form the start of a genetic selection for new breeds better adapted to local conditions. However, according to Silvia & Del Lama (1997), it is important to start selective breeding with widespread and well-adapted breeds rather than crossbred animals.

Milk production of Zebu cows varies widely between different areas and with production conditions (Malau-Aduli & Anlade, 2002). For example, Zebu cows in Brazil produce more milk (Silvia & Del Lama, 1997) than those in Burkina Faso (Sidibé-Anago *et al.,* 2006). In addition, Boly *et al.,* (2001) found very high variation between cows belonging to the Zebu Azawak type and concluded that some cows may be better suited for selection for milk production. Milk recording systems have been used to gather information for genetic purposes (Hare *et al,* 2004), but there is no such system based on breeding in Burkina Faso. Taking into account the variation in production between different types of Zebu cows (Malau-Aduli & Anlade, 2002; Belemsaga *et al.,* 2005), a recording system would be valuable for gathering national genetic information for the different breeds in Burkina Faso.

2 Biological aspects of milk production

2.1 Milk synthesis

Milk is produced by the mammary gland, which consists of secretory cells in a single layer epithelium forming spherical structures called alveoli. Increased milk yield in early lactation is the result of increased secretory activity per cell (Capuco *et al.,* 2001; see review by Capuco *et al.,* 2003), while the decline in milk yield with advancing lactation is explained by decreased numbers of secretory cells (Capuco *et al.,* 2001).

The nutrients needed for milk synthesis are provided to the udder by the blood (Wheelock *et al.,* 1965), thus blood flow to the mammary gland is an important factor in determining the amount of milk produced (Thompson & Thomson, 1977). It is generally accepted that 400-500 litres of blood need to pass through the mammary gland for the production of one liter of milk. Decreases in mammary nutrient uptake may be due to reduced mammary blood flow, a decrease in the ability of the gland to extract nutrients from the blood, or a combination of both factors (Guinard-Flament *et al.,* 2007). Stress, caused by hot or cold conditions or disease for example, can decrease mammary blood flow and thereby reduce milk production (Linzell, 1960). Milk yield increases rapidly from early lactation to peak lactation and then decreases until the cow dries off (Foley *et al.,* 1972; Mech *et al.,* 2008) and the shape of the lactation curve follows the same trend for different breeds of cows (Kay *et al.,* 2005).

There is a complex endocrine regulation of milk production, involving both systemic and local endocrine factors (Cowie, 1971). Prolactin is one of the most important hormones for maintaining milk production, and oxytocin is known to be the key hormone for milk ejection (Cowie, 1971). In addition, prolactin plays a role in maintaining established lactation (Knight, 2001), and both oxytocin and prolactin are released during milking (for review see Svennersten-Sjaunja & Olsson, 2005).

Water makes up about 87% of the total volume of cattle milk (Harding, 1999), with the other major components being fat, protein and lactose. According to Jenness (1985), the concentrations of the major components of bovine milk range on average between 3.8 - 4.9% fat, 3.0 - 3.6% protein and 4.6 - 4.8% lactose. However, there are large variations between breeds and stages of lactation.

Lactose, a disaccharide consisting of glucose and galactose combined in the Golgi apparatus of secretory cells (Kuhn, 1983), is secreted into the milk in Golgi vesicles together with milk protein, minerals and vitamins. Lactose attracts water to the milk and is thereby important for the total milk yield. Milk fat consists mainly of triglycerides synthesized from glycerol and fatty acids. Long chain fatty acids are absorbed into the mammary secretory cells from the blood while short chain fatty acids are synthesized in the mammary gland from acetate and beta-hydroxybutyrate, which have their origins in the ruminal fermentation of dietary carbohydrates (Larson *et al.,* 1956). Milk protein consists of approximately 80% caseins and 20% whey protein (Kirchgessner *et al.,* 1967). The essential amino acids are absorbed from blood while non-essential amino acids can be synthesized in the secretory cells of the mammary gland (Larson & Kendall, 1957).

2.2 Distribution of milk in the mammary gland

Synthesized milk is drained from the mammary alveoli in milk ducts, leading the milk towards the teat. In the ruminant mammary gland, the milk ducts empty into cavities known as the gland cistern in which milk can be stored after synthesis. In a full udder, milk also accumulates in the alveoli. The cisternal cavity of the mammary gland of dairy cows has been estimated to represent 20-40% of the total milk volume stored in the udder. The cisternal milk fraction can easily be removed during milking while the alveolar fraction is only available under endocrine control (Bruckmaier *et* *al.,* 1994). The proportion of storage capacity in the cisternal and alveolar compartments differs both within and between species. For example, primiparous cows usually have a smaller cisternal fraction than older cows, and the cisternal cavity is smaller in cows and buffaloes than in goats and sheep (Bruckmaier *et al,* 1994; Thomas *et al.,* 2005).

2.3 Physiology of milk ejection

Milk ejection is a neuro-endocrine reflex activated by sensory stimulation of the teats of the udder that causes release of the anterior pituitary hormone oxytocin (Ely & Petersen, 1941). When the increased blood oxytocin levels reach the mammary tissue, myoepithelial cells surrounding the mammary alveoli contract and milk is expressed into the cisternal area (Soloff *et al.,* 1980). The time from stimulation of the teats until milk ejection is usually 30-60 seconds (for review see Svennersten-Sjaunja *et al.*, 2004). The tactile stimulation of the teats can be replaced with other sensory stimuli connected to suckling or milking; sound, visual and olfactory signals (See review by Tancin & Bruckmaier, 2001). Milk ejection is quicker and more efficient if udder fill is high, thus milk yield and milking frequency affect milk ejection. There is a linear relationship between udder fill and the onset of milk ejection, and the delay until the start of milk ejection decreases with increased udder fill (Bruckmaier & Hilger, 2001). Milk ejection after stimulation of the udder in both low and high yielding cows is similar at the same stage of lactation (Wellnitz *et al.,* 1999). In addition to causing milk ejection, oxytocin participates in other physiological processes in lactating animals; it stimulates maternal interaction with the offspring and increases the attachment between mother and young (for reviews see Uvnaès-Moberg *et al.,* 2001).

Pre-stimulation before milking is needed to obtain good milk ejection and efficient emptying of the mammary tissue. It has been shown that manual pre-stimulation in dairy cows leads to higher peak concentration of oxytocin and a more rapid milk removal than milking without pre-stimulation (Gorewit & Gassman, 1985). Pre-stimulation is particularly important when machine milking is used as it ensures that milk ejection starts when the teats cups are attached, avoiding teat damage by milking on empty teats. In goats, pre-stimulation may not significantly influence the course of milk flow in the same manner as in cows (Bruckmaier *et al.,* 1994). Feeding during milking increases oxytocin release during the entire milking process (Svennersten *et al.,* 1995) resulting in better udder emptying. Higher and more prolonged oxytocin concentration was also reported for hand-milking compared to machine milking (Gorewit *et al.,* 1992).

Suckling is the strongest stimulus for initiating oxytocin release and milk ejection (Akers & Lefcourt, 1984; for review see Tancin & Bruckmaier, 2001). Udder washing can also stimulate milk ejection, and warm (30-32°C) and cold (13-15°C) water were found to be equally effective in stimulating oxytocin release during machine milking (Dzidic *et al.,* 2004).
Oxytocin must be elevated during the entire milking for efficient milk removal (Bruckmaier, 2001), and milking routines should thus be designed to obtain a good milk ejection and efficient milk removal. Milk ejection occurs faster in early than in late lactation due to udder fill. Milk ejection also occurs faster after long milking intervals, again because of higher udder fill. Suckling results in complete milk removal, and milk yield is higher in suckled than in non-suckled cows (Sandoval-Castro *et al.,* 2000).

2.4 Inhibition of milk ejection

Milk ejection is disturbed when oxytocin release is inhibited (Ely & Petersen, 1941) and pain, fear (Bruckmaier, 2001), cold stress (Linzell & Peaker, 1971) and food-deprivation (Svennersten *et al.,* 1995; Samuelsson *et al.,* 1996) all decrease or stop oxytocin release. Inhibition of oxytocin has been reported, for example, when cows are moved to unfamiliar surroundings (Macuhová *et al.,* 2002) or milked by a new person (Herskin *et al.,* 2004).

Cows are often intimidated or frightened in new environments (Grandin, 1997; Hopster *et al.,* 1998; Prelle *et al.,* 2004) and their reaction to new people is known to be more negative than that to a new environment itself (Herskin *et al.,* 2004). This leads to difficulties in milking the cows, and udder emptying is often incomplete (Bruckmaier *et al.,* 1993; 1996). Heart frequency and plasma cortisol increase and cows show clear signs of distress by stepping and urinating (Rushen *et al.,* 2001). Bruckmaier *et al.,* (1996) showed that oxytocin was not released at all during the first milking in unfamiliar surroundings, and only 13% of the expected milk yield was obtained.

2.5 Teat treatment

During milking, either by hand or machine, the teats can be easily damaged. Unsatisfactory milking conditions, such as high milking vacuum, ineffective pulsation, heavy clusters, unsuitable liners, poor teat preparation and over-milking are known to contribute to poor teat condition and increase the risk of intramammary infection (see review by Velazquez, 2000). It has been observed that machine milking can cause oedema in the teat, which persists for hours after milking is completed (Hamann *et al.,* 1993)

The first line of defense for the mammary gland is the epidermis of the teat (e.g. Zecconi *et al.,* 2005). Resistance to bacterial invasion of a mammary quarter is mainly determined by the structure and function of the teat canal (Sandholm & Korhonen, 1995), which has several anatomical features that act as barriers to penetration by bacteria. Teat morphology differs between breeds and has been linked to the incidence of mastitis, although without clear conclusions (see reviews by Seykora & McDaniel, 1985; Menzies & Mackie, 2001).

It is important to avoid injuries to the teat (Sandholm, 1995). Sandholm (1995) report that the growth of pathogens, such as *Staphylococcus aureus,* is lower in hand milked than in machine milked milk, suggesting that hand-milking causes less damage to the teats than machine milking does. Whether teat treatment varies between different hand-milking techniques is not known.

3 Aspects of milk yield and quality

Milk quality is a broad concept that generally encompasses composition, hygiene and the addition of chemical substances or water. The demands on quality can vary, and depend on the end use of the milk. Hygienic quality is naturally of great importance, since bacterial growth in milk during storage can be a health hazard for the consumer and can cause changes in milk composition through enzymatic activity (Ranieri *et al.,* 2009).

One of the consequences of genetic selection is increased milk yield per cow that is negatively correlated with fat and protein content (Gordon *et al.*, 1995). However, fat, protein and total solids yield are reportedly positively correlated when milk yield per cow is increasing (Whitlock *et al.,* 2003).

3.1 Factors influencing milk yield and composition

Milk yield is largely determined by genetic and nutritional factors, although milking frequency and efficiency of milk removal can significantly affect milk yield per cow (DePeters *et al.,* 1985; Gisi *et al.,* 1986), and frequent milking in combination with suckling increases total milk yield (Bar-Peled *et al.,* 1995). The relative day-to-day variation in milk yield for machine-milked dairy cows has been estimated at 6-8% (Syrstad, 1977; Sjaunja 1986), while similar variation in hand-milked cows has not been investigated in detail.

Milk fat is the most variable of the major milk components, varying between breeds (Bansal *et al.,* 2005), stage of lactation (Kay *et al.,* 2005), feeding (Whitlock *et al,* 2003) and during milking (Johansson *et al.,* 1952).

High yielding cows have lower milk fat content than low yielding cows (Auldist *et al.,* 2007), and milk fat content is higher in early and late lactation than in mid-lactation, being negatively correlated with milk yield (Kay *et al.,* 2005; Auldist *et al.,* 2007). Energy intake levels also influence fat content. A decrease in milk-fat concentration is common with diets rich in ground forage, high concentrate or unsaturated oil (van Soest, 1994). Milk fat content increases during milking, since it partially separates from the water in the milk during storage in the udder, thus efficient emptying of the udder during milking results in higher fat content in the milk obtained. In systems where the calf is allowed to suckle after milking, lower fat content has been reported in saleable milk (Sandoval-Castro *et al.,* 2000; Fröberg *et al.,* 2007). In machine milking conditions, relative day-to-day variation for milk fat content is 5-8% (Syrstad, 1977; Sjaunja, 1986).

Like fat content, milk protein content is influenced by breed (Bansal *et al.,* 2005), stage of lactation (Kay *et al.,* 2005) and nutritional factors (Whitlock *et al,* 2003) and is also higher in early and late lactation than mid-lactation, and negatively correlated with milk yield (Kay *et al.,* 2005; Auldist *et al.,* 2007). As with milk fat, protein content is reportedly higher in low yielding than high yielding cows (Auldist *et al.,* 2007). Increased energy intake, either by increasing the level of concentrates or by improving the silage quality, increases the protein content in milk (Waldo *et al.,* 1998), however it is much easier to modify milk fat than milk protein content by feeding. The relative day-to-day variation in milk protein is around 3%, lower than for milk fat (Sjaunja, 1986; Syrstad 1997). Lactose is the least variable component of milk (Linzell & Peaker, 1972) due to osmotic regulation that attracts water into the milk. The day-to-day variation in lactose in machine-milked cows was estimated to be just above 1% (Sjaunja, 1986).

3.2 Temperature and pH of milk

Cooling milk as soon as possible after milking is important for preventing bacterial growth (e.g. Foley *et al.,* 1972; Bachman & Wilcox, 1990), and cooling time and temperature were found to affect not only fresh milk but also milk for pasteurization and ultra-high-temperature (UHT) treatment (Griffiths *et al.,* 1988). The psychrotroph bacteria are able to grow at low temperatures and the storage-life of raw milk is influenced more by its initial psychrotroph count than by its initial temperature (Griffiths *et al.,* 1988).

The geometric mean pH of raw milk from healthy cows has been established to be 6.6 (Harding, 1999), but some studies report a range of 6.5-6.7 under different production systems (e.g. Gran *et al.,* 2002; Sraïri *et al.,* 2009). Increased milk temperature can decrease milk pH, and raw milk with pH $\leq$ 6.0 quickly coagulates and fails to pasteurize. Thus the importance of cooling milk under hot tropical conditions is very clear. In Burkina Faso, however, raw milk temperature has not been used for assessing milk quality, and farmers do not know to what extent milk may be spoiled when it is stored for long periods in hot conditions.

3.3 Milk hygiene and handling of raw milk

The quality of raw milk has been found to influence the dairy products (e. g. Desmasures *et al.,* 1997; Schroeder *et al.,* 2008). The key factor for quality dairy products is to avoid contamination of the raw milk and milk products (Elmoslemany *et al.,* 2009). Unfortunately, raw milk provides an excellent medium for micro-organism growth over a wide temperature range; psychrotroph bacteria at temperatures below 7°C, mesophilic bacteria at 25-37°C and thermophilic bacteria after heating to 60-80°C (e.g. Oliveira *et al.,* 2000). Thus to ensure food safety and public health, hygiene control is critical and involves feed hygiene, dairy farm practice, dairy processing and not least how consumers handle the milk (Valeeva *et al.*, 2005).

Farm environment, milkers, milking equipment and milk transport are all possible points of milk contamination (Tomasula & Konstance, 2004). In Burkina Faso, farmers either transport milk to the dairy unit or market themselves, or sell it to third parties, called milk collectors, who bring the milk to local markets or for processing. It was recently reported that the total bacteria in farm tank milk should be less than 10^3cfu/ml in Europe (Pantoja *et al.,* 2009), with the threshold differing between countries, but studies performed in African countries have concluded that milk hygiene is poor, often with total bacteria counts of 10^6cfu/ml in tank milk at farms (e.g. Kivaria *et al.,* 2006; Harouna *et al.,* 2008; Grimaud *et al.,* 2008).

4 Factors influencing udder health

4.1 Mastitis

Mastitis, an inflammatory reaction of the mammary gland caused by bacterial infection or tissue trauma (e. g Harding, 1999; Sandholm *et al.,* 1995), is the most common and economically costly disease in dairy farming (for review see Seegers *et al.,* 2003; Nielsen, 2009). It is a multifactorial disease, affected by management practices, exposure to pathogens and efficiency of the udder defense mechanisms as well as interaction between these factors (Harmon, 1994; Oviedo-Boyso, 2007). The most common route for pathogenic microorganisms to enter the udder is through the teat canal (Smith *et al.,* 1985). The subsequent damage to the tissue of the mammary gland increases the vascular permeability and results in an increased number of somatic leukocyte cells in the milk (Dohoo & Meek, 1982; Harmon, 1994). Dirty bedding constitutes a hygiene risk to udder health (Barberg *et al.,* 2007), and it was also reported that suckling improves udder health in suckled compared to non-suckled cows, probably due to improved udder emptying (Fröberg *et al.,* 2008)

Milk always contains a certain amount of somatic cells of various types, and their relative proportion depends on the health status of the cow (Harmon, 1994). Mastitis can be classified as acute or chronic, depending on the duration of the infection, and is further classified as clinical or subclinical (Dohoo & Meek, 1982). In subclinical mastitis, the udder and milk show no visible signs of inflammation, whereas clinical mastitis does, including redness, heat, pain and impaired function (Marshall *et al.,* 1993).

California Mastitis Test (CMT) (Marshall *et al.,* 1993), somatic cell count in milk (see review of Berglund, 2003; Berglund *et al.,* 2007), lactose (Linzell & Peaker, 1972) and lactate dehydrogenase content (Friggens *et al.,* 2007) are all used as indication methods for udder health status and mastitis. The CMT solution reacts with leukocytes and forms a gel (Marshall *et al.,* 1993) and the test is quick and easy to apply on farm. There is still discussion on the levels of SCC that indicate a mastitis risk. Harmon (1994) showed that above 200,000 cells/ml milk per cow, the risk for mastitis was increased, while others have suggested that SCC in milk from a healthy udder should be below 100,000 cells/ml milk (Lievaart *et al.*, 2007; Forsbäck *et al.,* 2009) and some authors have even mentioned 50 000 cells/ml per udder quarter (Hortet *et al.,* 1999; Merle *et al.,* 2007).

It is well known that good environmental hygiene (Barberg *et al.,* 2007), cleanliness of dairy cows, washing and dipping teats after milking (Hickey *et al.,* 2002) and good milking routines are important for ensuring udder health. Clean bedding, the housing system and stocking density are also important (Veissier *et al.,* 2004). In Burkina Faso, for example, the prevalence of mastitis was lower in small herds than large herds (Sidibé *et al.,* 2004).

4.2 Consequences of mastitis for milk production

Mastitis is a serious disease for the dairy industry causing economic losses for farmers (Nielsen, 2009) and impacting cow welfare. Clinical mastitis is associated with milk yield loss at the time of diagnosis and throughout lactation. Lactation yield losses of 4 to 6% in multiparous cows and 2 to 4% in primiparous cows have been reported (Hortet & Seegers, 1999). However, Wilson *et al.* (2004) show that, before diagnosis, mastitic cows have a production advantage over non-mastitic cows. Clinical mastitis also leads to decreased milk casein, lactose and fat content (Hortet & Seegers, 1999).

5 Aims of the thesis

The overall aim was to improve milk production and milk quality in Burkina Faso. First, the current dairy system was described, followed by separate studies focused on milking routines of local Zebu cows and raw milk hygiene in the dairy chain.

The specific aims were:

To identify the major problems limiting domestic milk production in Burkina Faso, with focus on peri-urban areas where demand for milk is highest.

To investigate variation in milk production and length of lactation between cows, day-to-day variation in milk yield and milk composition within cows in hand-milked and restrictedly suckled Zebu cattle, and suggest how this information can be used for improving milk production.

To discover whether different hand-milking techniques vary in their effect on teat condition, milk yield and milk composition.

To identify critical points for milk hygiene in the dairy chain.

Objectives of the studies

This thesis was built on three different types of study. The first was a survey (Paper I) investigating the current situation in dairy farming and milk processing in peri-urban areas of Burkina Faso. Two experimental studies (Papers II-III) and two field studies (Papers IV-V) were designed to answer questions from the survey.

The specific objective of the survey study (Paper I) was to investigate the possibilities for milk production and how milk is handled at dairy farm and dairy processing unit level. In addition, milk samples taken at farms and dairy processing units were analyzed for composition and somatic cell count.

The objective of the day-to-day variation study (Paper II) was to investigate day-to-day variation in milk yield, composition and somatic cell count (SCC) in hand-milked and restrictedly suckled local Zebu cows.

The objective of the milking technique study (Paper III) was to compare three different hand-milking techniques and their effect on teat treatment and milk production of Zebu cows.

The objective of the milk hygiene study (Paper IV) was to investigate total bacteria content in raw milk in the dairy chain from dairy cows to consumers, in order to identify important focus points for future milk hygiene programs.

The objective of the milk recording study (Paper V) was to investigate variation in milk yield and length of lactation in local cows in Burkina Faso.

6 Materials and methods

Burkina Faso is a West African country located between longitude 2°20´ East and 5°30´West and latitude 9°20´and 15°05´North, covering an area of 274,000 km^2. The climate is dry tropical with a 7-8 months long dry season and rainfall varying from year to year, between 400 mm and 1200 mm from the north to the south of the country (Guinko, 1984).

The survey study (Paper I) included peri-urban and urban areas of Ouagadougou and Bobo-Dioulasso (Figure 1). The two cities lie 365 km apart with total annual rainfalls of 700-800 mm and 900-1200 mm respectively. The dairy farms and dairy units included in the study were located no more than 50 km from the city centers.

The experimental day-to-day variation study (Paper II) was carried out at the Farako-Bâ research Center, 12 km South of Bobo-Dioulasso.

The milking technique study (Paper III) was carried out at a commercial farm in the village of Kimidougou, 15 km North of Bobo-Dioulasso.

The milk hygiene and milk recording field studies (Papers IV-V) were carried out in the peri-urban area of Bobo-Dioulasso.

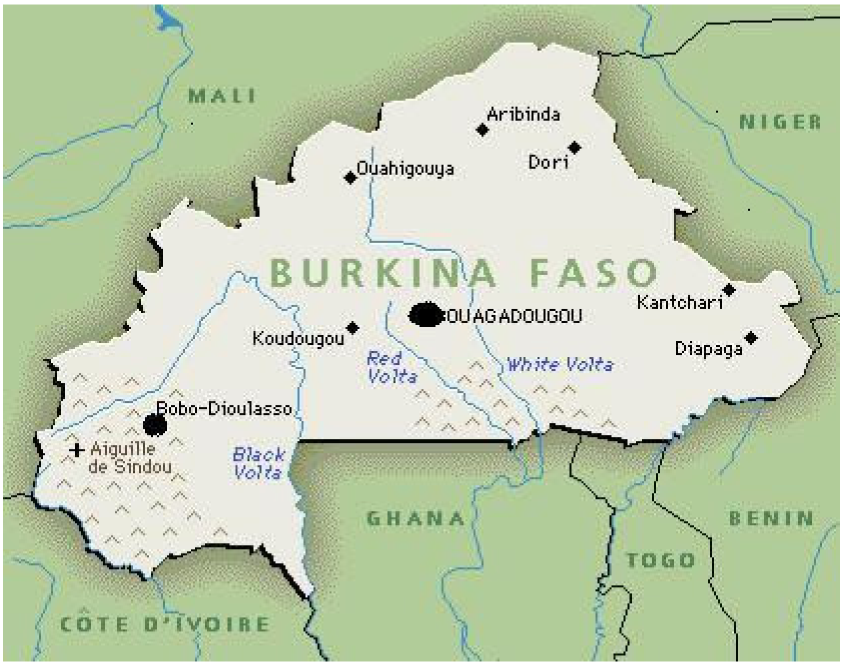

Figure 1: Map of Burkina Faso, location of study areas in Burkina Faso (1 = Ouagadougou area; 2 = Bobo-Dioulasso area). Adapted from United Nations (2004)

6.1 Animals, Housing and Feeding

6.1.1 Day-to-day variation study (Paper II)

Ten multiparous lactating Zebu cows in day 41±16 of lactation were included in the study. The live weight of the cows was between 228 and 296 kg and milk yield was 1.2-4 L/cow/day at the beginning of the study.

Before the study, the cows and their calves were treated against internal and external parasites and against trypanosomiasis. All cows and calves were housed in a barn. Cows were separated from their calves for most of the day and night and were only kept together during milking and for the post-milking suckling time. The cows were taken to natural pasture for four hours in the morning and two and half hours in the afternoon. In addition, the diet was supplemented with 4 kg DM grass hay, 1.5 kg DM cottonseed cake and 0.5 kg DM molasses, according to calculated requirements for maintenance and milk production (NRC, 1978). The supplemented diet was given during a two-week adaptation period and a four-week recording period. Water was offered *ad libitum* four times per day.

6.1.2 Milking technique study (Paper III)

The study was carried out in August and September 2008 with twelve lactating Zebu cows. All cows calved in July 2008 and were in days 20-30 of lactation at the start of the study. The animals belonged to a commercial farm where it was not possible to record body weight. Milk yield was between 1.2 and 2.5 L/cow/day at the start of the study.

All cows were treated against internal and external parasites and against trypanosomiasis. Housing conditions were typical for traditional peri-urban dairy farms in Burkina Faso. During the night, and at milking, cows were kept in a temporary enclosure. Cows were separated from their calves for the most of the day and night and were only kept together during milking and for the post-milking suckling times.

Grazing time was 10 hours per day and the same person took the cows for grazing and followed them when they were grazing throughout the experiment. In addition to pasture, the diet was supplemented with 1.5 kg cottonseed cake/cow/day, with supplementation level based on calculation of NRC (1978) and the proportion of cottonseed cake in the diet of the day-to-day variation study (Paper II).

The cottonseed cake was introduced gradually over 9 days with rations of 0.5 kg on the first three days followed by 1 kg for the following three days and finally 1.5 kg for a further three days. The cottonseed cake (0.5 kg, 1 kg and 1.5 kg) was given to cows on days 23, 17 and 14 respectively prior to the first day of the experimental recording period.

6.1.3 Milking routine

In both the day-to-day variation and milking technique studies (Papers II-III), cows were hand-milked twice daily. The udders were washed with water before milking, and calves were used for pre-stimulation of the udder to initiate milk let-down.

In the day-to-day variation study (Paper II), milking took place in the barn at 07:30 h and 17:00 h. The milking management routine prior to the experiment was twice daily milking.

Before the milking technique experiment (Paper III) began, all cows were milked once daily. Twice daily milking was introduced when the cows were in day 20-30 of lactation, 23 days prior to the first day of the experimental recording period (Paper III). Milking was done at 06.30 h and 16.30 h. Three different hand-milking techniques were applied: "full hand grip", "thumb in" and "pull down", based on those observed in the survey (Paper I) (Figure 2).

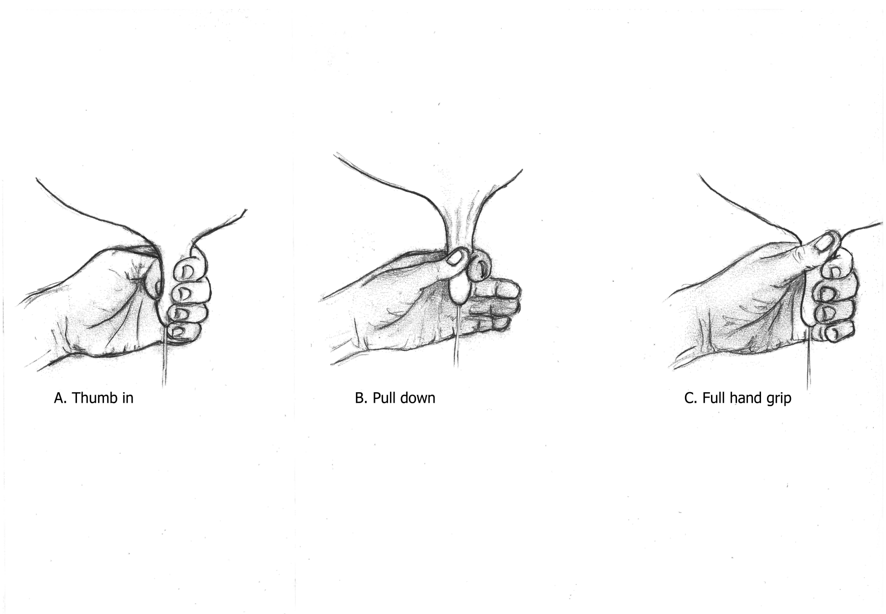

Figure 2: Illustration of the three hand-milking techniques compared in the hand-milking technique study. Illustration by Katarina Cvek-Hopkins (2009).

6.2 Experimental design

6.2.1 Survey study (Paper I)

The survey included twenty-two dairy farms and nine dairy processing units (Paper I); ten farms linked to six dairy processing units in the Ouagadougou area and twelve farms linked to three dairy processing units in the Bobo-Dioulasso area. Processing units that process local raw milk were identified and included. Dairy farmers with links to the processing units through selling milk to them were approached for participation. Interviews were carried out according to two separate questionnaires, one for dairy processing units and one for dairy farms, and were conducted by the same person throughout the study. The questionnaires for dairy farmers included 48 questions covering management, animal production, milk production, hygiene practices and milk transport for dairy farms. The questionnaire for dairy processors included 10 questions on aspects of milk processing and management of the dairy processing units.

6.2.2 Day-to-day variation study (Paper II)

Milk yield recording and milk sampling were performed at morning and evening milking. The study covered a two-week adaptation period for the supplementation diet followed by 30 consecutive days of recording and sampling. Milking was performed by two milkers, according to standard routines in the research barn. The two milkers were involved at the same time during each milking and were not specifically assigned to cows.

6.2.3 Milking technique study (Paper III)

The experiment (Paper III) was designed with twelve dairy cows (Zebu cow), three milkers and three treatments (milking techniques: "full hand grip", "thumb in") and "pull down" (Table 1). The overall duration of the treatment in each period was 8 days. The experiment included three periods, each starting with five days for adaptation to the milking technique followed by sampling over three days. The four cows in each technique group were milked by the same milker using the same technique both morning and evening. Milkers rotated between techniques and groups of cows each day. In the last three days of each period, milkers were assigned to a particular technique and rotated between cows so that every cow was milked by each milker each day, but in different sequences for the different cows.

Table 1: Experimental design of the hand-milking technique study (Paper III). T = Treatment (0 = “full hand grip”, 1 = “thumb in” and 2 = “pull down”). M=Milker (A, B, C). Milk yield was recorded on day 1-24, milk composition was determined on day 6-8, 14-16 and 22-24.

Period	Day	Cow																							
		0		1		2		3		4		5		6		7		8		9		10		11	
		T	M	T	M	T	M	T	M	T	M	T	M	T	M	T	M	T	M	T	M	T	M	T	M
0	1	0	A	1	B	2	C	0	A	1	B	2	C	0	A	1	B	2	C	0	A	1	B	2	C
	2	0	A	1	B	2	C	0	A	1	B	2	C	0	A	1	B	2	C	0	A	1	B	2	C
	3	0	A	1	B	2	C	0	A	1	B	2	C	0	A	1	B	2	C	0	A	1	B	2	C
	4	0	B	1	C	2	A	0	B	1	C	2	A	0	B	1	C	2	A	0	B	1	C	2	A
	5	0	C	1	A	2	B	0	C	1	A	2	B	0	C	1	A	2	B	0	C	1	A	2	B
	6	0	A	1	B	2	C	0	A	1	B	2	C	0	A	1	B	2	C	0	A	1	B	2	C
	7	0	B	1	C	2	A	0	B	1	C	2	A	0	B	1	C	2	A	0	B	1	C	2	A
	8	0	C	1	A	2	B	0	C	1	A	2	B	0	C	1	A	2	B	0	C	1	A	2	B
1	9	1	A	2	B	0	C	2	B	0	C	1	A	1	A	2	B	0	C	2	B	0	C	1	A
	10	1	B	2	C	0	A	2	C	0	A	1	B	1	B	2	C	0	A	2	C	0	A	1	B
	11	1	C	2	A	0	B	2	A	0	B	1	C	1	C	2	A	0	B	2	A	0	B	1	C
	12	1	A	2	B	0	C	2	B	0	C	1	A	1	A	2	B	0	C	2	B	0	C	1	A

	13	1	B	2	C	0	A	2	C	0	A	1	B	1	B	2	C	0	A	2	C	0	A	1	B
	14	1	C	2	A	0	B	2	A	0	B	1	C	1	C	2	A	0	B	2	A	0	B	1	C
	15	1	A	2	B	0	C	2	B	0	C	1	A	1	A	2	B	0	C	2	B	0	C	1	A
	16	1	B	2	C	0	A	2	C	0	A	1	B	1	B	2	C	0	A	2	C	0	A	1	B
2	17	2	A	0	B	1	C	1	C	2	A	0	B	2	A	0	B	1	C	1	C	2	A	0	B
	18	2	C	0	A	1	B	1	B	2	C	0	A	2	C	0	A	1	B	1	B	2	C	0	A
	19	2	B	0	C	1	A	1	A	2	B	0	C	2	B	0	C	1	A	1	A	2	B	0	C
	20	2	A	0	B	1	C	1	C	2	A	0	B	2	A	0	B	1	C	1	C	2	A	0	B
	21	2	C	0	A	1	B	1	B	2	C	0	A	2	C	0	A	1	B	1	B	2	C	0	A
	22	2	B	0	C	1	A	1	A	2	B	0	C	2	B	0	C	1	A	1	A	2	B	0	C
	23	2	A	0	B	1	C	1	C	2	A	0	B	2	A	0	B	1	C	1	C	2	A	0	B
	24	2	C	0	A	1	B	1	B	2	C	0	A	2	C	0	A	1	B	1	B	2	C	0	A

6.2.4 Milk hygiene study (Paper IV)

The milk hygiene study (Paper IV) was carried out in both the rainy and dry seasons. Samples were obtained at five levels of raw milk handling; dairy cows during milking, farm tank, milk collectors, local market and dairy processing unit tank. Milk samples were collected twice during each season from each milk handling. The selected dairy processing units and dairy farms were also included in first field study (Paper I). Milk sellers were randomly selected in two different local markets, and milk collectors were identified at dairy processing stages.

6.2.5 Milk recording study (Paper V)

Milk recording was carried out once per month from January 2008 to February 2009 on ten dairy farms around Bobo-Dioulasso in the West of Burkina Faso. Milk yield was measured separately in the morning and evening of the same day. On each farm, all lactating cows were included in the study, giving a total of 79 cows across the ten farms.

6.3 Recording and Analyses

6.3.1 Milk yield measurement, time for suckling and milking

Milk yield was measured with a 2 L ± 10 ml graduated test tube in the day-to-day variation study (Paper II), in the milking technique study (Paper III) and in the milk recording study (Paper V). Yield of saleable milk for individual cows was measured at each milking during 30 days and 24 days in the day-to-day variation study (Paper I) and in the milking technique study (Paper III) respectively. During the recording study (Paper V), yield of saleable milk was measured once per month by the same person at all farms. The time for calves to suckle for milk let-down and the total milking time were recorded with a stopwatch in the day-to-day variation study (Paper II).

6.3.2 Milk sample collection

Samples were put on ice for transport to the laboratory (about 20-45 min) and stored at 4°C (Paper II) and -20°C (Paper I-III) until determination of dry matter, fat, protein, lactose and SNF.

In the survey study (Paper I), milk samples were taken from individual cow milk, farm tank milk and dairy processing unit tank milk, collected in 100 ml tubes. In the studies where milk yield was recorded, milk samples were taken from saleable milk from individual cows at each milking. After measuring milk from individual cows (Paper II-III), a sample was taken in a 30 ml tube after mixing milk by pouring the milk back into the bucket and again into the 2 L test tube.

In the survey study (Paper I) and milk hygiene study (Paper IV), milk samples were taken in 100 ml and 30 ml tubes respectively. Milk in buckets, with milk from individual cows, farm tank milk and dairy buckets was mixed twice before pouring into the sample tubes. For milk collectors in the milk hygiene study (Paper IV), milk samples were taken at the reception of milk at the dairy. In the local market (Paper IV), milk samples were taken by mixing the bucket milk. At the dairy processing unit and local market, mixing of milk was done by the dairy person or seller. In the day-to-day variation study (Paper II), strip milk samples from separate quarters were collected when milking was considered to be complete, while in the milking technique experiment (Paper III), pooled strip milk samples were collected, representing all four quarters of the udder.

6.3.3 Analysis of milk samples

Milk temperature, pH and somatic cell count were determined directly on farm, at dairy processing units (Papers I-III-IV) or at the research center barn (Paper II). Milk temperature and pH were determined using pH-meters; metrohlm, 704 Ch-9101, Herisau, Switzerland in Paper I and Jenway 370 pH-meter, European Union in Paper IV.

Milk samples were stored at -20°C before analysis in the survey study and the milking technique study (Papers I-III). Frozen milk samples were slowly thawed and warmed to 38°C, then mixed (Cenco Instrumenten B.V, Breda-Netherland) in order to obtain an even fat emulsion before analysis. In the day-to-day variation study (Paper II) and the milk hygiene study (Paper IV), milk samples were stored at +4°C for one day before analysis.

Milk fat, protein, lactose, DM and SNF were determined using a portable mid infra-red spectroscopy instrument (FMA 2001, Miris AB, Uppsala, Sweden). Somatic cells were also determined with a portable instrument, using a fluorescence method (DeLaval Cell Counter, DeLaval, Tumba, Sweden). Petri-film count plates were used for determination of total bacteria count (3M Petrifilms GmbH Hammfeldamm, Neuss, Deutschland) in Paper IV. Hemoglobin in milk was analyzed in Paper III (Hemocue AB, plasmas/low B photometer, Ängelholm, Sweden).

6.4 Statistical analysis

The difference between variables was considered statistically significant at $P < 0.05$ (Papers I-II-III-IV).

The statistical analysis in Paper I was performed with the Statistical Package for the Social Sciences (SPSS) for Windows (version 14:02, 1989-2005). Data was coded according to Nancy *et al.* (2005). Frequencies were established for qualitative variables and mean, standard deviation, minimum and maximum values were obtained for SCC, pH, temperature, fat, protein, lactose, DM and SNF. The Chi-square test was used to test relationships between variables.

The data analysis in paper II was performed with the statistical analysis system (SAS Institute Inc Cary, NC, USA, 2002-2003). The analyses were performed on the whole data set and also on sub-sets of data from samples with SCC above or below 200,000 cells/ml. This threshold was set based on Harmon (1994), who has suggested that the 200,000 cells/ml threshold could be used to distinguish healthy udders from mastitic ones.

Data from the milking technique study (Paper III) were analyzed with the statistical analysis system (SAS Institute Inc Cary, NC, USA, 2002-2003). Successive elimination of non-significant interaction and carry-over effects were performed by removal of the least significant effect at each step.

The statistical analysis in Paper IV used Minitab version 15 with the general linear model procedure (GLM), and mean values were compared using Tukey´s pairwise comparison procedure.

The recording data (Paper V) was subjected to descriptive statistics using Minitab version 15. Average milk yield and standard error of the mean was calculated for milk yield separately for the different breeds identified in the material.

7 Main results

7.1 Milk production and management system (Papers I-IV-V)

The survey study (Paper I) revealed two types of farming system in peri-urban areas of Burkina Faso. Traditional farming represented 55% of farmers and semi-intensive farming 45%. The farming system was related to the type of farmer. In the traditional system, farmers generally had a sub-primary school education with low levels of literacy. They were full time farmers, working together with their families and owned mainly local cattle breeds for milk production. The cows were indigenous Zebu breeds (*Bos indicus*), along with Baoulé and N´dama (*Bos taurus*). Farmers in the semi-intensive system were better educated, often public sector workers and business people that were new actors in the dairy farming industry. Farming was a part time activity for this group, they used both crossbreds and indigenous breeds and had employees who managed the animals on a daily basis.

In the traditional system, animals were managed according to the farmers' knowledge, and farmers were traditionally specialized in animal production. There was no built barn for dairy cows, which instead were kept in temporary enclosures during the night. This was in contrast to the semi-intensive system where farmers hired workers for grazing, milking and other tasks and there was a built barn where animals were kept at night and during milking.

Production based on natural grazing pasture was common to both production systems. In addition, supplementation of concentrate to lactating cows was practiced, and feed sources consisted of crop by-products such as cottonseed cake or corn bran. Supplementation was also related to the capacity of farmers to invest in farming. In traditional farms, animals obtained water from rivers close to the grazing areas, whereas animals owned by part time farmers obtained water from drill holes on farm.

The average number of animals per herd was 76 ± 22 (standard deviation). Traditional farming was characterized by a high number of animals, with a high proportion of non-producing cows and a higher number of heifers, whereas the number of animals in the semi-intensive system was limited by the capacity of the barn. It was more common to use bulls for reproduction than artificial insemination, with farmers in both systems using one or two bulls. Forty five percent of farmers had never used artificial insemination for reproduction, while most of the 55% that had tried artificial insemination had experienced failures.

The milking routine consisted of hand-milking in combination with restricted suckling. On all farms, calves were used for udder pre-stimulation; the calf was then taken away from the teats and tied when milking started. At the end of milking, calves suckled for a limited time until the dam went to pasture. Milking routines differed between the traditional and semi-intensive production systems (i.e. udder washing, number of milkings per day, different ways to remove milk). In addition, three ways to milk cows by hand were observed; "pull-down" (N =15), "thumb in" (N= 6) and "full hand grip (N =1). Pull down was most common while thumb-in and "full hand grip" were used by only a few farmers. The time for calves to stimulate milk let-down was 1.5 minutes on average (Paper II) without significant variation between morning and evening milking. Longer milking time was recorded in the morning (8 minutes) than the evening (7 minutes) (Paper II).

The survey revealed that the price of one liter of raw milk was higher in the dry season (0.55-0.77 USD) than in the rainy season (0.44-0.66 USD). Milk transport time was one to two hours depending on the distance between farm and dairy processing unit, and farmers used bicycles or motorcycles to transport milk from the farm to the dairy or milk collecting center.

The dairy processing units had little experience (5 to 10 years), and low daily processing capacity (100-150 L). The dairy products were mainly yogurt and pasteurized fresh milk. In spite of the selection criteria, it was found that only seven of the nine dairy processing units included in the study used raw milk alone for processing, with the other two sometimes using imported milk powder. The marketing system was based on social relationships and the provision of information to consumers and shops.

7.2 Milk yield (Papers I-II-III-V)

Milk yield was not measured in the survey, but based on farmers' knowledge about their production both per cow and per day. Milk yield was estimated at 1-2 L/cow/day in traditional farms and 2-4 L/cow/day in semi-intensive farms (Paper I). The average daily yield per farm was 20 L and 40 L in traditional and semi-intensive farms, respectively. Some semi-intensive farmers said that cross-bred cows could reach 10 L/cow per day. Daily saleable milk yield recorded in the day-to-day variation study was on average 2 L/cow/day with a minimum of 0.6 L/cow/day and a maximum of 4 L/cow/day (Paper II). The day-to-day variation calculated for morning and evening milk yields was 21% and 18% respectively. Morning milk yield was on average 1.3 L and evening milk yield 0.8 L.

In the milking technique study (Paper III), the saleable milk recorded for morning and evening was on average 1.3 L and 1.0 L per cow, respectively. Daily milk yield did not differ between the three hand-milking techniques. Milkers obtained different quantities of milk, and milk yield depended on an interaction between milker and treatment.

Data from the pilot milk recording (Paper V) showed a large variation in milk yield between cows in Burkina Faso. The variation was higher in the other groups (Zebu Gir, Azawak, Gudali) and crossbred cows than in the indigenous Zebu. Only saleable milk was measured, excluding calf suckled milk. The highest daily yield in indigenous Zebu cows was 5.5 L per day while the highest for cross-bred cows was 5.2 L.

7.3 Composition of saleable milk and strip milk (Papers I-II-III-IV)

An overview of the fat, protein and lactose content of saleable milk in the different studies is given in Table 2. In the survey (Paper I), analysis of milk samples showed a range of 2.5-6.1 % fat, 2.8-4.5 % protein, 4.1-5.3% lactose, 11.4-15.5% dry matter and 8.1-9.3% SNF. The average fat content in milk from the Ouagadougou area (5%) was higher than from the Bobo-Dioulasso area (4%) ($P < 0.05$), but pronounced differences between areas in protein and lactose content were not found.

In the day-to-day variation study (Paper II), there was an effect of day on percentage of fat content of morning milk and percentage of protein in both morning and evening milk ($P < 0.05$). Milk composition was 4.8% fat, 3.4% protein and 4.8% lactose for morning milk, and 5.5% fat, 3.3% protein and 4.7% lactose for evening milk. The relative day-to-day variation in fat, protein and lactose content was 23%, 12% and 7% respectively for morning milk and 25%, 14% and 7% for evening milk. In the strip teat milk, fat content was 7% with a relative day-to-day variation of 19-46%.

The results of the milking technique study (Paper III) showed that different hand-milking techniques did not result in different milk fat, protein or lactose contents during either morning or evening. The average fat, protein and lactose contents were 4.3%, 3.6% and 4.8% for morning milk and 4.7%, 3.6% and 4.9% for evening milk. In addition, milk fat content (7-7.4%) was higher in strip milk than in saleable milk.

In the milk hygiene study (Paper IV), milk fat content ranged from 4-4.7% across the dairy chain in the rainy season and 3-4% in the dry season (Table 2). The range included individual cow milk, farm tank milk, local market and dairy processing unit. The concentration of milk protein was 3-3.9% and 3-3.6% for rainy and dry seasons respectively (Table 2). Lactose content was 4-4.9% and 4-4.7% for rainy and dry season respectively (Table 1) and the difference between seasons was not significant. Market milk had lower fat and lactose content in the rainy season than in the dry season ($P < 0.05$).

7.4 Somatic cell count (Papers I-II-III-IV)

Milk somatic cell count was on average 5.0 (log_{10} SCC) (100, 000 cells/ml) and 5.3 (log_{10} SCC) (199, 000 cells/ml) in milk samples from Bobo-Dioulasso area and Ouagadougou area respectively, but the difference was not significant (Paper I). Milk SCC was higher in farm tank milk samples than individual cow milk samples. The average SCC was 100, 000 cells/ml milk across all samples but higher SCC (800,000-1,000,000 cells/ml milk) was recorded in some milk samples from both individual cow milk and from farm tank (Paper I). There were no significant differences in milk SCC in the milk hygiene study (Paper IV) between samples from individual cow milk, farm tank milk, collectors churn milk, local market milk and processing units. The average milk SCC was 5.00 (log_{10}SCC) (100,000 cells/ml milk) and the difference between rainy and dry seasons was not significant.

In the day-to-day variation study (Paper II), the relative day-to-day variation in milk SCC was 8%. The average SCC in the day-to-day variation study was 4.8 (log_{10} SCC) (63,000 cells/ml). When SCC was below 200 000 cells/ml milk according to the threshold of Harmon (1994), fat, protein and lactose contents were not affected compared to the overall data set. However, when SCC was equal to or above 200, 000 cells/ml(log_{10} SCC = 5.6 = 398, 000 cells/ml in Paper II), milk, yield, fat and lactose contents were significantly lower ($P < 0.05$) than in samples with lower SCC. Protein content was not affected however (Table 3).

SCC did not differ significantly between milkers or treatments in the milking technique study (Paper III). The average SCC in saleable milk was 5.1 (log_{10}SCC) (125, 000 cells) in the morning and 5.2 (log_{10}SCC) (158, 000 cells/ml) in the evening. In addition to milk SCC, the presence of blood in milk was evaluated by measuring hemoglobin (Paper III). The hemocue technique revealed at 5% higher hemoglobin content in evening milk and 16% higher in strip milk samples compared to saleable milk. The interaction between milkers and treatments was significant for hemoglobin content, and hemoglobin content depended on how the milker applied the hand-milking technique.

7.5 Milk hygiene (Papers I-IV)

The survey (Paper I) revealed that washing the udder before milking was commonly done by only 13 farmers. The udder was washed when a cow looked dirty, as defined by the farmer. Only two farmers practiced teat dipping. In addition, it was observed on certain farms that some milkers put their fingers into the milk in the bucket to facilitate milking.

Milk temperature was around 30°C at all sampled levels, with higher variation in the Ouagadougou area than in the Bobo-Dioulasso area (Paper I). No cooling system was observed at farms in the study. In the milk hygiene study (Paper IV), milk temperature was 25°C and 26°C in dairy processing unit milk tanks and at local markets respectively. The average milk temperature was 29-30°C and 27-30°C in individual milk and farm tank milk respectively in both rainy and dry seasons (Paper I-IV).

The average milk pH was 6.7 (Paper I) and the range was 6.5-6.8. There was no significant difference between areas ($P > 0.05$). Milk pH in dairy processing unit tank milk was 6.6-6.7 (Paper I). In the milk hygiene study (Paper IV), the average pH of individual cow milk was 6.5 and 6.6 in the rainy and dry seasons respectively. The pH of farm tank milk, collectors churn milk, local market milk and milk from processing units was 6.6-6.9 and 6.5-6.9 in the rainy and dry seasons respectively (Paper IV).

In the milk hygiene study (Paper IV), the total bacteria count of raw milk from individual cows was on average 10^4 cfu/ml ($\log_{10}$TBC = 3.6) and 10^5 cfu/ml ($\log_{10}$TBC = 4.5) in the rainy and dry seasons respectively. Total bacteria count did not differ significantly ($P > 0.05$) between milk samples from farm tank, dairy processing units, collector churn milk and local market buckets. The total bacteria count was 10^6cfu/ml and 10^7 cfu/ml in milk samples from rainy and dry seasons, respectively (Paper IV).

Table 2: Composition of saleable milk in the different studies of the thesis (Paper I-II-III-IV).

Study area	Paper	Fat (%)	Protein (%)	Lactose (%)
Ouagadougou	I	5.1	3.4	4.7
Bobo-Dioulasso	I	3.8	3.4	4.9
IN.E.R.A Barn	II	4.8	3.4	4.8
Kimidougou	III	4.3-4.7	3.6	4.8-4.9
Bobo-Dioulasso	IV $_{(min)}$	3.4	3.4	4.3
	IV $^{(max)}$	4.7	3.9	4.9

Table 3: Mean somatic cell count, total bacteria count, milk temperature and pH as indictors of milk hygiene quality in the different studies of the thesis (Papers I-II-III-IV).

Study area	Paper	$\log_{10}$SCC (cells/ml)	pH	T °C	$\log_{10}$TBC (cfu/ml)
Ouagadougou	I	5.3	6.7	30.5	-
Bobo-Dioulasso	I	5.0	6.7	30.0	-
	II $_{(min)}$	4.8	-	-	-
IN.E.R.A Barn	II $_{(max)}$	5.6	-	-	-
Kimidougou	III	5-5.2	-	-	-
	IV $_{(min)}$	5.0	6.5	25.5	3.6
Bobo-Dioulasso	IV $_{(max)}$	5.5	6.98	30.3	8.2

8 General discussion

8.1 Milk production system

Dairy production research in Burkina Faso progresses slowly due to limited access to facilities, laboratories and equipment, and advances in the management of indigenous breeds are accordingly slow. Most of the milk is produced by traditional farmers scattered across the country. Reliable research on raw milk and milk production requires good equipment, which is often unavailable, especially in rural areas. Consequently, milk production research in Burkina Faso has been concentrated in the peri-urban areas where farms are close to the city (Marichatou *et al.,* 2002; Boly *et al.,* 2001; Sidibé *et al.,* 2004; Mattoni *et al.,* 2007) and it is possible to transport milk samples to the cities. There are limited resources for animal research in Burkina Faso; for example there is no permanent dairy herd linked to any of the universities. Therefore, it is difficult to study important factors such as calving interval, lactation length and the total productive life of cows. This data is likewise not available in commercial herds, since there is no livestock identification system in place and no efficient records of dairy production.

Dairy production is one of the most important animal derived food production systems in many countries. Many aspects of dairy farming have been thoroughly investigated and dairy production has, in most parts of the world, undergone a highly technological development. The present study took place in a developing country where the production system is traditional with low technical development due to the economic and social situation. Development of these types of systems is extremely important

since it will contribute to reducing poverty and increasing animal food production for growing populations (Delgado *et al.,* 2001).
The development of milk production is highly dependent on the demands and possibilities inherent to the different production systems (International Dairy Federation, 1990). The survey study (Paper I) was carried out to highlight the needs and possibilities for the development of peri-urban milk production systems close to the main cities of Burkina Faso. In these areas the urban population is increasing, creating a market for dairy products, reflected by a slight increase in the number of dairy farms (Marichatou *et al.,* 2002).

Milk production was carried out in both traditional and semi-intensive production systems in the peri-urban areas (Paper I) which agree with the findings of Sidibé *et al.* (2004) and Mattoni *et al.* (2007) who characterized dairy farms in the peri-urban area of Bobo-Dioulasso in Western Burkina Faso. In the present survey, milk processing units were included since they also play an important role in the dairy chain. Limiting factors for milk production in Burkina Faso were found both at farm level and at processing level. Feeding, lack of infrastructure, lack of farmer training, low milk hygiene, unsatisfactory management of dairy cows and low milk yield per cow were the major problems found at dairy farms (Paper I). Lack of facilities, such as drills for water, barns for cows and electricity were also observed at farms.

The use of natural pasture as the main feed source is a serious obstacle to meeting the maintenance and production requirements of dairy cows. This grazing system limits productivity because cows often have to walk long distances to graze and thereby use energy that otherwise could have gone to milk production. Indeed it has been shown that extreme walking conditions can result in lower milk yields (Coulon *et al.,* 1998). The pasture system could be developed if farmers settle and own land for cultivating their own grasses. In such systems it is important to limit the number of animals per unit area to avoid over-grazing.

Problems with moving animals from one over-grazed area to new areas, causing erosion and desertification, has been described as a consequence of livestock farming in the Middle East (Olsvig-Whittaker *et al.,* 2006). Similar problems could arise in Burkina Faso, which is located in the Sahelian zone and challenged by drought. A shift towards organized grazing would require farmer education that is not yet in place (Paper I). Supplementation with concentrate was practiced on some farms in our study, and was linked to slightly higher milk yield (Paper I), however it is costly for farmers to feed cottonseed cake, for example, to low yielding cows (Sidibé-Anago *et al.,* 2006). It is important to keep in mind that concentrates supplementation without efficient milking will not result in higher milk yield. It is likely that hand-milking will be practiced for another ten years or more, since electricity is unavailable in most rural areas of Burkina Faso.

Processing units collected low amounts of milk and had very low processing capacity (Paper I). It is difficult to collect a large amount of milk without good storage and cooling systems. Dairy processors had to process the milk gradually as it was received from farmers and collectors. In the rainy season, processing units had more milk for processing than they could sell, even if they managed to process it (Oudet, 2005 unpublished data) while in the dry season, shortages due to poor pasture (Kaboré-Zoungrana *et al.,* 1999) meant that the amount of milk available was insufficient for continuous processing. With the recent high world market price of milk powder and the global financial crisis, demands on domestic milk production and processing have increased. The main question now is how to solve the seasonal variation of milk production and make local milk available for year round processing.

It is vital that farmers have knowledge about the milk production of each cow to be able to tailor feeding and management to each individual, but also to accurately evaluate the production capacity. Calving interval, calf birth weight, measured milk yield per cow and lactation length are all important management factors that farmers did not record or control (Paper I). In addition, farmers were unable to keep a dairy herd improvement book because of their low education level. The high proportion of non-lactating cows in the dairy herds shows that reproduction is not well managed. The most common reproduction management system was the use of bulls, with only a small number of farms using artificial insemination.

While it might be beneficial for farmers to plan calvings, the poor synchrony of lactation between cows suggests that this was not done. It could be achieved either by restricting the bulls' access to cows until several are in oestrus and having them mate several cows during a short period, or by artificially synchronizing oestrus in several cows. A higher number of cows lactating at the same time would lead to more efficient management, and would allow calvings to be concentrated at the time of the year when farmers are paid most for milk.

8.2 Milking management

Possibilities to increase milk yield per cow by improving management and milking of dairy cows were important goals identified by the survey study (Paper I). The common practice for farmers (Papers I-V), and in our experimental studies (Papers II-III), was restricted suckling where the calf was used for initiation of milk ejection and also suckled after milking.

Suckling has been shown to have a beneficial effect on milk yield (Das, 1999¸ Fröberg *et al.,* 2008) and may also improve udder health (for review see Krohn, 2001; Fröberg *et al.,* 2008) compared to non-suckled cows. Lower fat content was reported in saleable milk in restrictedly suckled cows (Fröberg *et al.,* 2007). It is known that pre-stimulation routine (Rasmussen *et al.,* 1992), type of teat stimulation during milking (Svennersten *et al.,* 1990) and an increase in milking frequency in combination with suckling (Bar-Peled *et al.,* 1985) all increase milk yield.

The present study showed that the amount of milk per cow mainly depends on the ability of the milker rather than on the milking technique (Paper III). The different hand-milking techniques ("pull down", "thumb in" and "full hand grip") all yielded similar amounts of milk per cow (Paper III), indicating that teat stimulation and udder emptying were equally efficient. There were probably slight differences in the way different milkers applied the techniques, and suckling behavior may have differed between calves, resulting in differences in the milk volume consumed (Paper III). In addition, there may have been differences between cows in how they responded to the calf, for example an ability to hold milk for the calf has been proposed (Das *et al.,* 2000; Fröberg, 2008). It is difficult to estimate the amount of milk suckled by the calves, and this was not prioritized in the milking technique study since focus was on the effects on the yield of milk for human consumption.

It is known that oxytocin concentration is elevated for 1-7 minutes during milking (Bruckmaier *et al.,* 1994; Bruckmaier, 2001; Weiss *et al.,* 2003). Filipovic & Kokaj (2009) found for hand and machine milking 6 and 4 minutes respectively. In the day-to-day variation study (Paper II), the time for hand-milking was 7-8 minutes. Bruckmaier & Wellnitz (2008) state that, in machine milking, it is important to consider the time from the start of tactile stimulation until milk ejection. This has been estimated at 30 to 60 seconds (for review see Svennersten-Sjaunja *et al.*, 2004). The time for calf stimulation was recorded in Paper II as 60 to 90 seconds. Differences in milking time between hand and machine milking could be caused by differences in oxytocin release, differences in milk flow or a combination of both.

More frequent milking of dairy cows increases milk yield (Depeters *et al.,* 1985; Bar-Peled *et al.,* 1995; Patton *et al.,* 2006). In the survey study (Paper I), very few farmers practiced twice daily milking but calves had access to cows for suckling more than once a day. Our conclusion is that farmers should milk their cows more than once a day, but the higher milk yield is likely to be accompanied by higher nutrient requirement (Depeters *et al.,* 1985). In the current production conditions of Burkina Faso, the problem of limited feeding probably needs to be solved before milking more frequently than twice daily could be introduced.

There are several factors that reduce a cow's milk production. Even though cows were milked twice daily in some of our studies (Papers II-III) and in other studies (Bar-Peled *et al.,* 1995; Patton *et al.,* 2006), the effect of once and twice daily milking has not been thoroughly investigated for Zebu cattle in Burkina Faso. Incomplete milking is known to reduce milk production, probably due to a feed-back inhibition mechanism exerted by a particular milk protein on the secretory cells when milk is present in the mammary alveoli (Wilde *et al.,* 1995). Milk yield increases when cows are milked frequently due to the removal of this protein, the feedback inhibitor of lactation (FIL). Frequent removal of milk makes it possible for the secretory cells to be active and therefore milk yield increases (See review by Capuco *et al.,* 2003). In a system where restricted suckling is practiced, as in Burkina Faso, suckling after milking, and between milkings if included in the management system, most likely helps in avoiding the effects of FIL. This is supported by the work of Fröberg *et al.* (2007) who found that cows that were milked once daily in combination with restricted suckling twice daily produced more saleable milk than cows milked once daily without restricted suckling.

8.3 Milk recording

Our study found a relatively large day-to-day variation in milk yield within cows (18-20%) (Paper II). Most of the day-to-day variation in saleable milk yield is likely to be an effect of the management system with hand-milking and restricted suckling. Information on daily variation within cows is important in order to evaluate information from farms, for farmers, milk collection centers and researchers. This information could for example be used to design a farm milk recording system.

Knowledge about normal variation allows early detection of illness and management problems (for review see Svennersten-Sjaunja *et al.,* 1997), and is also valuable for research planning, for example in order to test the power of experimental designs. Information from recording can be gathered in dairy herd improvement systems, and be used for selection by starting with a nucleus herd (Peixoto *et al.,* 2006). This is also the way to construct a national recording system in Burkina Faso, based on breeds, feeding, milk yield and milk composition.

Regular milk recording is an important tool for selective breeding, feeding and animals management (Hare *et al.,* 2004). We observed that farmers were unable to carry out recording of milk yields themselves (Paper V), and lacked the necessary equipment. This is not surprising since most farmers had low education level (Paper I). To obtain milk-recording data, farms in the pilot milk recording study (Paper V) were visited once per month. After seven months of lactation, all the cows included in the study were still lactating (Paper V). The majority of the animals in the study were indigenous Zebu cattle, and our data suggest that the lactation length of the Zebu does not have to be as short as previously reported (Yilma *et al.*, 2006). The pilot recording data also indicated large variations between cows (Paper V). Large variation in milk yield between cows was also recorded by Boly *et al.* (2001) in the peri-urban area of Ouagadougou. This large variation in milk production between cows is relevant for genetic selection, since some cows are higher yielders than others and can thereby be used for improvement of the herd (Silva & Del Lama, 1997; Peixoto *et al.,* 2006).

Farmers in the milk recording study were asked to milk their cows twice a day, which is known to increase milk yield per cow. Milk yield and lactation length can be improved by increasing nutrient intake when cows are high yielding, and by using better milking routines. The results from the pilot milk recording study differed from those of Boly *et al.* (2001), who found that only 11% of Zebu Azawak were still lactating after 200 days. Twice daily milking was applied by Boly *et al.* (2001), and we have no specific explanation for the differences between the results from the two studies. However, feeding, type of Zebu cow and management conditions could all play a role. For example, Das (1999) reported longer lactation length in Zebu cows that calved in the dry season than in the rainy season. The rich availability of grasses in the rainy season provides a high nutrient intake and, under similar milking and management, lactation is more prolonged than in the dry season.

8.4 Milk components

Milk fat and milk protein yields from processing are very important for the dairy industry and are often used to assess the quality of milk from farms. In four of our studies, milk fat and protein contents varied greatly between cows (Papers II-III) and between farms (Papers I-IV). The composite milk from farm tanks (Papers I-IV) was the mixed milk of several cows of different ages, parity and stage of lactation. Overall, the individual cow milk fat, protein and lactose contents were in agreement with those of Bonfoh *et al.* (2005) in Mali and Sidibé-Anago *et al.* (2006) in Burkina Faso. The higher fat and protein contents compared to Holstein-Friesian milk could be related to genetic characteristics of the breed, lower milk yields and nutritional conditions (Bonfoh *et al.*, 2005).

Day-to-day variation in milk fat and protein has not been previously reported in hand-milked and restrictedly suckled cows. Milk fat content in strip milk (Papers II-III) was lower than reported from hand and machine milked cows (Svennersten *et al.,* 1990). This could be explained by the degree of udder emptying, and less residual milk due to suckling (Svennersten *et al.,* 1990). In our studies (Papers II-III), a strip milk sample was taken after milking and before the calf was allowed to suckle. It is known that fat content increases during milking (Johansson *et al.,* 1952), and it is therefore important to complete milking if possible. However, the high fat milk expressed at the end of milking provides valuable nutrition for the calves.

The overview provided by our studies (Papers I-II-III-IV) shows that milk composition is not a major problem for milk production in Burkina Faso. Unexpectedly however, low fat, protein and lactose contents were observed on some farms (Paper I), at the local market level (Paper IV) and at some processing units (Papers I-IV). At farm level, this may be due to problems with feeding, udder health or incomplete milking. Unbalanced diets and mastitis are also known to decrease fat (Bauman & Griinari, 2003) and lactose contents (Linzell & Peaker 1972) in severe cases. At local market and processing unit level, low fat, protein and lactose contents may be due to the addition of water to the milk, but our study could not prove that this was the case. Further, it cannot be excluded that the milk at markets and dairy processing units was bovine milk mixed with milk from other species, which would also affect milk composition.

8.5 Milk hygiene

Milk temperature was high on the farms and during transport since no cooling system was in place (Paper I). Accordingly, milk hygiene was a problem both at farms and processing units. Similar observations were made by Marichatou *et al.* (2002) who report that the number of dairy farms in peri-urban areas increased without any control of milk hygiene. It is well known that cooling milk inhibits bacterial growth, but the cooling temperature must be adjusted in order to maintain milk quality during processing (Griffiths *et al.,* 1988). Milk pH did not vary greatly in our studies (Papers I-IV), and was in agreement with other studies on farm and at processing unit levels (Gran *et al.,* 2002; Sraïri *et al.,* 2009). Milk pH and temperature are simple and easy criteria that could be used by dairy processors in Burkina Faso to determine milk quality at reception. This could reduce the risk of receiving milk with lower pH and mixing this with the whole tank milk for processing.

The hygiene of raw milk along the dairy chain was evaluated using its total bacteria count. The average total bacteria count was high (10^6-10^7 cfu/ml) with low variation between samples (Paper IV). The results are in agreement with those found by Aaku *et al.* (2004), Grimaud *et al.* (2008) and Little *et al.* (2008) under similar production conditions. The explanation was that raw milk was produced in uncontrolled environments with no udder washing (paper I) and possibly unclean milking vessels during storage and transport. Lower total bacteria counts were observed in milk obtained directly from cows. This was expected since milk from cows is known to be sterile if they do not have mastitis. Thus, bacterial contamination occurs outside the udder. In our study, contamination could start immediately when the milk is drawn from the cow to the bucket because teats, milkers' hands and milk buckets were not cleaned.

The cfu/ml in milk at dairy processing units and markets were so high that they pose a severe risk for to consumers, and could be due to bacteria established inside the milk storage containers. The design of the plastic containers used on most farms, with a narrow mouth and hollow handle, makes them difficult to clean properly. Milk processors have a responsibility to collaborate with farmers or collectors to provide an appropriate, easy to clean container that minimizes bacterial establishment during milk storage at the farm. A cleaning procedure must be strongly recommended at farm level, and milk should be brought as quickly as possible for processing. Hygiene practices should be applied in order to minimize contamination of raw milk.

8.6 Udder cleaning, milk somatic cell count and teat treatment

With uneven milking equipment and lack of endocrine control, teat tissue can be easily damaged. In our study (Paper III), we measured blood content of milk as an indicator of teat tissue damage during hand-milking. We used a photometric method available as a portable instrument. The method was easy to apply under the local conditions, but no reference values for bovine milk are available so the results should be interpreted cautiously. Nevertheless, the results agreed closely with those of Rasmussen & Bjerring (2005) who reported 0.4% blood in milk samples. At this level, milk was described as pink when compared to milk samples without blood. Blood in milk may cause rejection of the product for processing or consumption and acts as a substrate for bacterial growth. Furthermore, the presence of blood in the milk indicates teat tissue damage that increases the risk for infection in the udder. Mastitis is known to be costly for milk production in low yielding (Omore *et al.,* 1999) and high yielding systems (Nielsen, 2009). The new analytical method to assess blood in milk used in our study is promising because it is simple to use on farm, but is not yet sufficiently well documented.

The final serious management problem identified by our survey (Paper I) was the routine for cleaning udders before milking. It is known that cleaning the udder before milking decreases the bacteria count of raw milk and improves udder health, often reflected by low milk SCC (See review by Pankey, 1989; Ingawa *et al.,* 1992).

In our study, milk SCC was used as an indicator for mastitis (Papers I-II-III-IV). Many farmers did not clean the udder before milking, but milk SCC was generally much lower than in previous studies in Burkina Faso (Traoré *et al.,* 2004) and in Mali (Bonfoh *et al.,* 2005). However, mastitis is usually found in only one quarter of the udder at a time (Barkema *et al.,* 1997), and milk SCC often differs between udder quarters. A healthy quarter should have less than 100, 000 cells/ml (Forsbäck *et al.,* 2009). Milk SCC levels as low as 100,000 cells/ml milk in cow composite milk, as observed in our studies (Papers I-II-III-IV), may therefore be related to subclinical mastitis (Green *et al.,* 2001). It is likely that the restricted suckling conditions in our study were beneficial for udder health compared to non-suckled cows (Fröberg *et al.,* 2008).

Another factor affecting mastitis incidence is herd size. Sidibé *et al.* (2004) found higher mastitis incidence in large dairy herds compared to small herds in Burkina Faso. Our study included both large and small herds, according to the definition of Sidibé *et al.* (2004). The grazing system in which cows are kept in the barn for only a few hours a day may be one of the main reasons for the relatively low somatic cell counts. High stocking density was one explanation of higher SCC found by Traoré *et al.* (2004) in Burkina Faso, since the dairy herd was close to the city with very limited land available.

8.7 Implications of the results and challenges for milk production

This thesis clearly shows that the production system in Burkina Faso is basic in nature, and many problems with the management of dairy cows exist. However, several positive factors were identified, such as low SCC indicating good udder health, the interaction between calves and cows during milking and suckling, and that cows were not confined in small barns because of the grazing system. In systems with low milk yield, farmers should benefit from improved management of the suckling system, avoiding both mastitis and unnecessary calf death.

In traveling from farm to farm, it became clear that there is a discrepancy between research findings and what farmers actually do in the field. It is important to link farmers and farms to advice services that can provide knowledge and gather information from farms. Our results show that the following important issues need to be solved.

Firstly, farmers should be trained and given access to a continuous advice service. The pilot recording study showed how great the need is for a country-wide recording system that could provide information for genetic selection in the different types of dairy cows. It is important that farmers accept participation in such a national recording scheme, but in reality this will probably depend on their education level and the perceived benefits of participation, such as advice on how to improve their production.

It is important to improve feeding, as concluded by previous studies in Burkina Faso (Sidibé-Anago, 2008; Ouédraogo-Koné, 2008). When farmers focus on milk production, which is the case in peri-urban areas, they might apply at least twice daily milking. The generally lower SCC observed may be the result of suckling, and this practice should be maintained in the management of such low yielding systems (Pegram *et al.,* 1991; Sandoval-Castro *et al.,* 2000; Fröberg *et al.,* 2008). Calf growth rate has been reported to be higher when calves are suckled than when reared artificially (Das, 1999; Fröberg *et al.,* 2008).

Finally, this thesis represents only a small contribution to solving a broad and complex problem, and many more studies are needed. It is important to note that the response of milk yield to genetic selection will be better if feeding, housing, milking frequency, milking routine and cow health are well controlled by farmers. All these challenges need to be solved in Burkina Faso and, if they are successfully combined, increased and improved farm production capacity can be achieved.

9 General conclusions

The main limitations to milk production in peri-urban areas of Burkina Faso are: low availability of feed and water, lack of selective breeding, milking management and the lack of infrastructure.

The variation in milk production between animals suggests that milk production could be improved through selective breeding, and monthly milk recording should be applied for this purpose. Because of the large day-to-day variation in milk production, more frequent milk recording would be useful for improving cow management.

Different hand-milking techniques did not differ in their effect on teat treatment, milk yield or milk composition. However, the hand-milking techniques suited different milkers to different extents.

There were low total bacteria counts and low somatic cell counts in milk from individual cows, indicating good udder health. Milk was contaminated after milking, and the total bacteria count was dangerously high when the milk reached the consumers. The contamination problems need to be solved by improved handling of milk between the cow and the consumer.

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12 Summary in French (Résumé)

Production laitière des bovins laitiers à la traite manuelle au Burkina Faso

Résumé

L´objectif global de cette thèse était l´amélioration de la production laitière et des pratiques de la traite au Burkina Faso. Le Burkina Faso a une longue tradition d´élevage avec aujourd´hui un cheptel bovin important. Malgré ce potentiel laitier, l´importation de la viande et surtout des produits laitiers démontrent le besoin croissant d´améliorer la production nationale. Dans cette thèse, il a s´agit d´investiguer à travers une enquête, la situation réelle des fermes laitières, de la transformation du lait local dans les zones périurbaines du pays. C´est ainsi que deux études expérimentales et deux études de terrain ont été conduites pour répondre à certaines contraintes établies par les résultats de l´enquête. Les variation quotidiennes du rendement laitier de la vache et de la composition chimique du lait ont été déterminées en utilisant 10 vaches de races zébu. Trois techniques de traite manuelle ont été comparées utilisant 12 vaches de race zébu dans un modèle incluant trois trayeurs. L´enregistrement continu des quantités de lait par vache a été conduite sur 79 vaches provenant de 10 fermes laitières. La deuxième étude de terrain a porté sur l´hygiène du lait le long de la chaîne de production, de la vache jusqu`à la laitérie ou au marché local.

Les résultats des différentes études indiquent qu´une faible disponibilité alimentaire et le manque de race sélectionnée exclusivement pour la production laitière, la gestion de la traite et le manque d´infrastructures adéquates sont les principales contraintes qui entravent la production laitière dans les zones périurbaines du Burkina Faso. La traite est manuelle a été observée aussi bien dans les fermes traditionnelles que semi-intensives avec un allaitement restreint du veau après la traite. L´étude pilote sur l´enregistrement régulier des quantités de lait par vache a permis de savoir qu´il y a une large variation entre vaches et qu´il est possible d´améliorer la production laitière des vaches à travers une sélection génétique continue. A cet effet, l´enregistrement mensuel serait applicable pour des objectifs de sélection. En plus, la variation quotidienne du rendement laitier d´une même vache était largement supérieure (18-21%) chez les vaches traites manuellement avec un allaitement restreint que les résultats précédemment rapportés sur celles traites à la machine (6-8%). Par conséquent, un enregistrement plus rapproché des quantités de lait serait nécessaire afin d´utiliser les données pour améliorer la gestion des vaches. Aucune différence significative n´a été observée entre les trois techniques de traites manuelles appliquées ("traite par étirement des trayons", "traite à la main entière par pression sur la mamelle sans étirement des trayons", "traite utilisant uniquement la puce et l´index par pression de la mamelle sans étirement") sur la quantité de lait ou la composition chimique et les conditions sanitaires des trayons. Cependant, chaque technique de traite semble marcher en fonction du trayeur. De manière générale, un faible taux de cellules somatiques du lait a été observé indiquant de meilleures conditions sanitaires de la mamelle. La contamination du lait juste après la traite était caractérisée par un taux très élevé de la flore microbienne (10^6-10^7 cfu/ml) indiquant un risque élevé pour le consommateur.

Mots clés: Ferme, Zébu, vache, traite, composition du lait, transformation du lait, taux de cellules somatiques, allaitement restreint, enregistrement du lait, hygiene du lait.

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